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# An Era of Lasers- Application of Erbium Lasers in Pediatric Dentistry

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***Abstract:***
*Over the years, dentistry has evolved from conventional 'Extension for Prevention' approach for tooth preparation to minimally invasive methods of caries removal. In pediatric patients, dental phobia and anxiety is most commonly related to the sound and vibration of conventional rotary instruments. Lasers play an integral role in both minimally invasive dentistry and reduction of dental anxiety in patients. Erbium laser technology is a safe device for selective and efficient removal of carious tooth structure. This is especially important in pediatric dentistry, considering the morphology of the deciduous and young permanent teeth. The capability of caries removal without any distress to the patient has a huge impact on the delivery of dental care. Erbium lasers work by the principle of thermomechanical ablation, which allows selective removal of carious tooth structure. Apart from reduction of dental phobia, these lasers can also be employed for laser analgesia, decontamination and to significantly improve the properties of adhesive restorations. A review of literature over 20 years concerning the use of erbium lasers for caries removal was completed. This paper focuses on providing a comprehensive knowledge of the properties and application of erbium lasers in pediatric dentistry.*
***Keywords:*** *lasers, erbium lasers, pediatric dentistry*

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## I. Introduction

Dental caries is one of the most inflicting oral diseases of childhood. It leads to functional and aesthetic impairment in a child, which compromises the child's quality of life [1].The dental treatment is quite challenging in children as they lack in emotional and intellectual development leading to behavioral problems. Such dental fear related to operative procedures translates into avoidance of dental treatment, which causes deterioration of the child's oral health.

This has encouraged searching for newer techniques and materials to replace the traditional concept of 'Extension for prevention' approach given by Dr. G. V Black [2]. The advent of modern concepts of caries management, the concept of 'Prevention of Extension' has gained popularity. Minimally invasive dentistry is based on the concept of removal of only the infected carious tissue, while conserving as much tooth structure as possible.

Lasers are an integral part of minimally invasive dentistry. Laser stands for 'Light Amplification by Stimulated Emission of Radiation. Lasers differ from ordinary beam of light in terms of their monochromaticity, unidirectional nature, coherence and tremendous amount of energy. Lasers are used in dentistry for diagnostic and treatment purposes. Their use for intra-oral soft tissue procedures includes:incision, coagulation, periodontal surgeries, treatment of aphthous ulcers and herpetic lesions. They are also utilized for treatment of hard tissues such as selective caries removal, cavity preparation, apicoectomy, osseous surgeries etc. [3].

Earliest attempt to use lasers for removal of dental hard tissue was by Dr Leon Goldman, in the year 1964 [4]. Ruby lasers, developed by Maiman, were the earliest type of lasers to be used in dentistry. Such lasers used solid ruby as an active medium which was energized by a power unit. However, they required a high power source and were proven to be less efficient. In 1990, the Nd:YAG lasers designed specifically for the dental market were released. These lasers along with CO2 lasers and semiconductor diodes were successful in the treatment of soft tissues. However, they failed to ablate dental hard tissues [5]. Later, on May 7$^{th}$ 1997, the Food and Drug Administration provided clearance for the marketing of the first dental hard tissue laser, the Erbium lasers [6].

The idea of substituting a drill with a laser light in Pediatric dentistry brings the possibility of safe and minimal removal of carious tissue with better patient acceptance. In the last few years, several studies related to the application of erbium lasers have been conducted, by testing various parameters of erbium lasers. This review presents the current knowledge in the application of erbium lasers in the field of pediatric dentistry in a comprehensive manner.

## II. Erbium Lasers

Erbium family of lasers used in dentistry includes the erbium-doped yttrium-aluminum-garnet (Er:YAG) of wavelength 2940-nm and the erbium, chromium–doped yttrium-scandium-gallium-garnet (Er,Cr:YSGG) of wavelength 2780-nm. Er:YAG constitutes of a solid active medium of pure crystals of yttrium-aluminium that are intentionally doped with erbium atoms. Er,cr:YSGG is composed of solid active medium of crystals of yttrium, scandium and gallium intentionally doped with erbium and chromium atoms. The difference in the wavelength of these two erbium lasers results in a significant difference in water absorption between the two lasers. The Er:YAG wavelength is at the peak of water absorption in the infrared spectrum whereas the Er,Cr:YSGG exhibits approximately one third less absorption. In addition, the Er,Cr:YSGG laser has significantly deeper thermal penetration into the tooth structure [7].

Erbium lasers are capable of being used on both hard and soft tissues. They have the most FDA clearances for a host of dental procedures. They use water as their primary chromophore, but hydroxyapatite absorption also occurs to a lesser degree. Photothermal interactions are mainly utilized in soft tissue procedures and photodisruptive interactions in hard tissue procedures.

### 2.1 Mode of Action of Erbium Lasers in Minimally Invasive Dentistry

In 1989, Hibst and Keller found that water molecules and hydroxyapatite crystals efficiently absorb Erbium laser energy [8].The wavelength of erbium lasers matches the absorption peak of water. Such wavelength interaction with water in hard tissue causes the conversion of laser energy to heat and results in water vapour formation, which expands and produces high pressure inside the target tissue resulting in instantaneous micro explosions and ejection of particles of tissue. This process, called as thermomechanical ablation, is responsible for the use of lasers in minimally invasive dentistry [9, 10].The water absorption rate of erbium lasers is 8-10 times greater than that of CO2 laser and 20,000 times greater than that of Nd:YAG lasers [11].

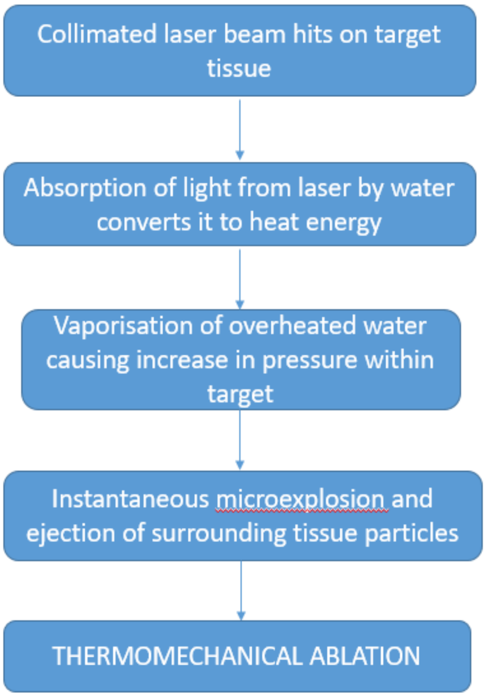


**Figure 1:** Mode of action of erbium lasers

### 2.2 Difference in Ablation of Tissues

Carious tooth structure is known to have more water content compared to sound enamel or dentin [12].Therefore, when laser of same parameters is applied on both sound and demineralized or carious tooth structure, the ablation rate of the carious and demineralized tissue is found to be considerably higher than sound tooth structure [13,14].This results in selective removal of carious tooth structure, which is the principle of minimally invasive dentistry.

Er:YAG shows difference in ablation of enamel and dentin. A higher absorption coefficient and lower ablation threshold for Er:YAG laser to dentin was found compared to enamel tissue. This results in faster and higher mass removal, using the same parameters, in the dentin, compared to enamel. This evidence could be explained by the difference of water and apatite mineral content and resulting laser–tissue interaction between both the tissues.

Additionally, difference in ablation rate can be observed between peritubular and intertubular dentin. When erbium laser is irradiated on dentin, there is greater removal of intertubular dentin compared to peritubular dentin [15]. This can be attributed to higher mineral and reduced water and collagen composition in peritubular dentin, whereas the intertubular dentin contains a higher water and collagen and lower mineral composition.

**2.3 Histopathological appearance of erbium laser irradiated tooth surface**

The erbium lasers promote effective thermomechanical ablation of both enamel and dentin. Macroscopically, cavities prepared by erbium lasers are conservative in configuration and allow maximum maintenance of dental hard tissues [16]. These cavity preparations are ideal for restoration using adhesive materials.

The enamel surface of a primary or a permanent tooth irradiated with erbium laser at 150-250 mJ with air/water spray shows open enamel prisms, with a characteristic honey-comb like or a lava flow [17] like appearance. This is mainly due to complete opening of prism core with partial destruction of interprismatic structure, due to the difference in the mineral composition between the two. The peripheral enamel may show irregularity due to the fragility of the prisms [18]. Additionally, the dentinoenamel junction shows the presence of open enamel prisms in a transverse direction [19].

Irradiated dentin surface appears irregular, with open dentinal tubules of various diameters. Irregularity in dentin results in a scaly or a flaky surface with no smear layer formation. This appearance is similar in both primary and permanent teeth. Histopathological studies show that dentin irradiated with erbium lasers presents an altered superficial layer (5–15 lm), called the modified ablation layer [20]. This layer is composed of microfragments and intense impregnation of basic fuchsine, indicating increased dentinal permeability and suggesting degeneration of collagen fibers. There is no evidence of burning, melting,cracking or any thermal damage on both enamel and dentin [18].

**2.4 Parameters of application of Erbium Lasers in Hard tissues**

Erbium lasers are applied on hard tissues in a non-contact mode, i.e., the terminal part of the handpiece is held 5-15mm away from the target tissue. It houses a unique lens that focuses the laser beam on the target tissue. Laser energy can be delivered through sapphire tip or a quartz fibre (600 microns diameter) or a sapphire ceramic tip (0.8 mm diameter). The Er:YAG laser pulses are grouped in four pulse widths: VSP (Very Short Pulses)-140 µs, SP (Short Pulses)-330 µs, LP (Long Pulses)- 550 µs and VLP (Very Long Pulses)- 920 µs .For deciduous teeth, 400-600 microns diameter is used for short pulse duration for 100-300 microseconds.Low dosimetries are used to remove caries, and high dosimetries are used to cut dentin and enamel. This lets operators remove the carious dentin without removing the sound dentin, until they decide to increase the energy and cut dentin or enamel. Table indicates the parameters of erbium lasers used in deciduous teeth [21].

It is used along with an air/water spray. According to Hibst and Keller, a water flow rate of 1 ml/min- 2 ml/min is adequate for a low pulse repetition and energies ranging from 150–250 mJ [22].At high energy of 700 mJ, a flow rate of 12ml/min should be used.The air water spray increases the ablative efficiency of the laser by aiding in microexplosion and vaporisation of enamel prisms [23].By enabling cooling of the dental tissues, it prevents micro and macro-structural damage to the dental tissues and pulp due to the increase in temperature caused by erbium lasers [24]. Therefore, the air/water spray plays a role in both increasing the amount of tissue ablated and protecting the tooth from undesirable thermal damage [25]. Inadequate water flow results in a burning smell that may irritate the patient.

**Table 1:** Parameters of Application of Erbium Lasers in Deciduous Teeth

| CLINICAL INDICATION | PULSE FREQUENCY(Hz) | ENERGY(mJ), POWER(W) |
|---|---|---|
| Carious tissue | 20-25 | 75-80 mJ, 1.5-2.0 W |
| Cavity preparation- enamel | 25-30 | 150-200 mJ, 3-4.5 W |
| Cavity preparation- dentin | 15-20 | 100-120 mJ, 1.8-2W |

**2.5 Advantages of Erbium Lasers in Pediatric Dentistry**

**a. Laser analgesia**

When erbium lasers are used at a near-infrared wavelength (803-980nm) in a defocused mode, they can produce analgesia lasting for about 15 minutes in the irradiated area, without any adverse pulpal changes. This is caused by temporary loss of impulse conduction due to disruption of $Na^+/K^+$ pump on the cell membrane of nerves [26]. In restorative dentistry, for optimum analgesic effect, the laser tip is held 6-10mm away from the tooth, and the tip is slowly moved across the neck of the tooth for 40-60 seconds at 25-50 mJ, 10-15Hz at a low air/water ratio. Post this, the energy can be increased at a focused mode for ablation of the tooth [27].At a low pulse rate of 10 Hz, laser energy can pass through the hydroxyapatite crystals to the pulp, where its energy pulses interact with type C and associated fibres of dental pulp. This is especially important in pediatric patients, since it obviates the need of administration of local anesthesia. Further, no additional equipment is required to produce analgesia.

**b. Reduction of dental phobia**

Vibration, sound and sight of conventional rotary instruments are the most common factors related to dental phobia in children. Erbium lasers are known to produce minimum level of vibration and noise during cavity preparation. Moreover,unlike the conventional rotary instruments that produce continuous vibration, erbium lasers produce pulsed vibration. High speed drilling causes 400 times greater vibration speed compared to that of erbium lasers, due to which the patient experiences pain [28]. Studies have indicated that children are more comfortable with erbium lasers over high speed drilling owing to absence of noise and vibratory sensation [29,30]. Additionally, they experience no contact between the fibreoptic tip and the tooth surface.

**c. Selective removal of carious tooth structure and minimal damage to pulp**

In pediatric dentistry, minimally invasive methods of removal of caries is extremely important owing to the small size of the crowns and the pulpal morphology of deciduous and newly erupted permanent teeth. According to Zach and Cohen, thermal damage to the pulp occurs when the change in temperature is greater than 5.5°C [31]. Such thermal injury can result in neurogenic inflammation and hyperemic increase in pulpal blood flow, which could eventually lead to necrosis. When erbium lasers are used in non-contact mode with water spray, they cause an increase in temperature of less than 3°C [27,32]. Pulpal response to cavity preparation caused by erbium lasers is minimal and reversible compared to high speed drill [33].Moreover, no pulpal inflammation can be noticed immediately or 30 days after laser preparation [34].

**d. Surface characteristics of cavity preparation**

Laser ablation (low energy level of 65-75 mJ, 400-600 microns tip) results in formation of a cavity preparation with macro-roughened surface, which increases the surface area for bonding with adhesive restorative material.Hence, it can be used in conjunction with acid etching for increasing the surface area of the preparation by roughening the surface. Additionally, absence of smear layer results in a clean and decontaminated surface that increases the bond strength of the restorative material [35].When surface pretreatment is done using erbium lasers prior to using self-etching adhesives, significant reduction in microleakage is noted [36].Hence, cavity preparation using laser helps in improving the retention rate of the restorative material.

**2.6 Laser Safety**

1. During laser treatment, it is mandatory for the dental operator, patient and dental assistant to wear protective goggles, which should cover the entire periorbital area. The protocol for use is 'patient first on and last off', that is, the patient should wear the goggles as soon as he is seated on the dental chair, and should take it off only after the procedure is completed.
2. The tooth should be isolated using rubber dam.
3. Reflective surfaces should be reduced.
4. Reusable fibres and tips need to be heat sterilized, disposable tips to be discarded in sharps container.

**2.7 Demerits of Erbium Lasers**

1. On an average, the time required for cavity preparation using erbium laser is 2.35 times greater than that required using conventional burs [37]. Therefore, such significant difference in time required may become inconvenientfor a pediatric patient.
2. The laser beam does not curve. Therefore, it is difficult to remove caries from the walls of the cavity preparation using laser alone. Moreover, the cavity margins cannot be finished using lasers. Therefore, curettes and conventional burs may be required for complete caries removal and finishing the margins of the preparation.

3. Application of erbium lasers is highly technique sensitive and requires training. Moreover, safety guidelines while using lasers should be followed by both the operator and the patient. Any stray radiation from the laser beam may affect the cornea or the eye lens, since both tissues are rich in water.
4. The cost and level of expertise required for using the machinery is high.

## III. Review of Literature

To conduct this review, over 25 articles (PubMed indexed) published since the past 20 years were reviewed. These articles included both in vitro and in vivo studies, conducted on permanent and deciduous teeth to test the parameters determining the efficiency of application of erbium lasers, in terms of caries removal using minimally invasive approach. The review was conducted using information obtained from both full articles and abstracts.

**Table 2:** Distribution of articles on basis of nature of text

| | Abstract | | Full Articles | |
|---|---|---|---|---|
| | In vivo | In vitro | In vivo | In vitro |
| Primary teeth | - | 2 | 2 | 2 |
| Permanent teeth | 2 | 5 | 5 | 1 |
| Both | 3 | - | 3 | - |

**Table 3:** Distribution of articles on basis of patient comfort related parameters

| | Patient comfort | Post-operative sensitivity | Pain assessment | Need for Local Anesthesia | Patient preference |
|---|---|---|---|---|---|
| No of articles reviewed | 11 | 5 | 4 | 5 | 2 |

**Table 4:** Distribution of articles on basis of erbium laser for cavity preparations related parameters

| | Time required | Safety | Vibration | Antibacterial properties | Caries removal efficiency | Surface characteristics | Anatomic form of preparation | Thermal changes |
|---|---|---|---|---|---|---|---|---|
| No of articles reviewed | 9 | 1 | 1 | 2 | 6 | 9 | 3 | 3 |

**Table 5:** Distribution of articles on basis of post-operative efficiency of restoration related parameters

| | Retention of restoration | Marginal discolouration | Marginal adaptation | Acid etching | Secondary caries | Micro leakage |
|---|---|---|---|---|---|---|
| No of articles reviewed | 5 | 3 | 2 | 6 | 4 | 2 |

## IV. Discussion

### 4.1 Patient related factors

According to a study conducted by Boj et al [38], pain perception is significantly low when erbium lasers are used compared to conventional rotary instruments. Further, in another study conducted by Kato et al [39], the pediatric patients who refused to be treated by burs showed better cooperation when they were treated with erbium lasers. Several studies have shown that patients often do not report with post-operative sensitivity when treated with erbium lasers. A study conducted by Keller et al [40] on 103 patients, shows that 79% of patients found mechanical tooth preparation to be uncomfortable compared to erbium lasers. In a study conducted by Liu et al [37], out of 40 pediatric participants, 90% preferred laser as cavity preparation tool in the next visit. Further more than two-thirds of dentinal cavity preparations were considered comfortable. However, some patients may find the smell of erbium lasers to be disturbing.

### 4.2 Laser Preparation related factors

A study conducted by Visuri et al [41] inferred that erbium lasers do not cause irreversible damage to the pulp, since erbium lasers cause temperature increase of less than 3°C, compared to conventional burs that cause an increase of 5°C. Several studies have proven that the time required for caries removal using laser is significantly greater than rotary burs [37, 40, 42]. Studies have indicated that the caries removal capacity is directly proportional to the energy of laser used [12]. However, a study conducted by Valerio et al [43] demonstrated that the efficiency of caries removal in deciduous teeth using erbium lasers is significantly less compared to conventional burs. Due to the lack of tactile sensitivity, the operator needs to continually verify the presence of residual infected dentin using curettes. Various microbiological studies designed to test the bactericidal ability of different laser systems have demonstrated that erbium lasers provide the best results in terms of reduction in the levels of E. coli, E. faecalis and other micro-organisms. Therefore, these lasers are suitable for decontamination of dentin surface in cavity preparation [44].

### 4.3 Restoration related factors

Currently there is some controversy regarding the procedure of composite restorations after the application of erbium lasers for cavity preparation. Some authors believe that acid etching should be performed after application of erbium lasers for caries removal, since it reduces microleakage at the restoration-enamel interface and results in the removal of superficial degeneration zone of dentin produced by these lasers [45, 46]. However, some researchers have reported that there is no need for acid etching or primer application for composite restoration in laser-treated teeth, since the laser irradiation of enamel produces an effect called as 'laser etching', which performs similar to phosphoric acid etching [42, 47]. In terms of microleakage and marginal adaptation, no significant difference can be observed between laser and etched bur cavities [42, 48]. According to a study conducted by Yazici et al [49], 100% retention rate was reported for laser prepared composite restorations and 98.1% for restorations prepared by burs. Erbium lasers aid in prevention of secondary caries by increasing resistance to acid demineralization, thus reducing the acid dissolution of dental hard tissues [50].

## V. Conclusion

Dental Phobia related to the conventional method due to sight, noise and vibration can be easily overcome with the use of Laser technique. But the time required for application of erbium lasers is greater than conventional instruments. The quality of cavity preparation and post-operative restoration efficiency has proved to be comparable to the conventional method. After several years of research and improvement, erbium lasers have proven to be safe technology in successful treatment for carious teeth, especially in pediatric patients. Hence, laser supported pediatric dentistry is one of the most promising fields of minimally invasive dentistry.

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